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SWITCHING THE CIRCUIT OF AN INDUCTIVE ENERGY STORE USING A VACU--ETC(U)
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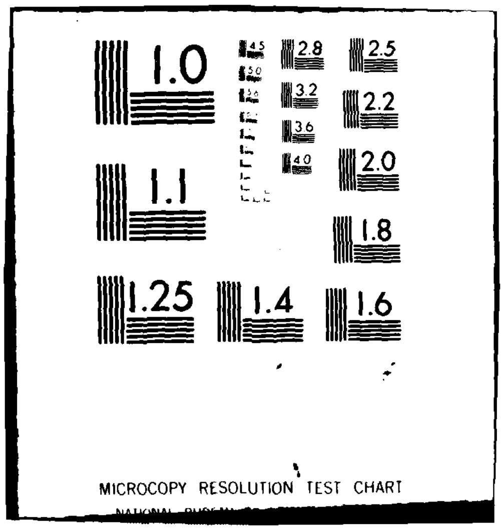
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FOREIGN TECHNOLOGY DIVISION

SWITCHING THE CIRCUIT OF AN INDUCTIVE ENERGY STORE USING A VACUUM SWITCH

by

A. V. Reymers, A. A. Tsvetkova, et al.

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

1960,gw

SWITCHING THE CIRCUIT OF AN INDUCTIVE ENERGY STORE USING A VACUUM SWITCH

A. V. Reymers, A. A. Tsvetkova, Yu. P. Ivanov, and V. P. Zhil'tsov

Moscow

When using a pulse generator with an inductive energy store great difficulties are caused by the effective breaking of its electrical circuit. It is interesting to investigate the possibility of using a vacuum switch for this purpose [1]. As is known, extinguishing of an arc in a vacuum switch takes place at the moment of passage of the current through zero. In the case of installation of such a switch in direct-current circuits (in particular, in a pulse generator with an inductive energy store) the transition through zero is achieved by the use of a special extinguishing device which is a capacitor bank discharging to the switch at the necessary moment [2]. The expediency of using a switch of a given type in the circuit of an inductive energy store is determined to a significant

degree by the size and cost of the auxiliary capacitor bank. The basic task of this article is to determine the necessary energy of the capacitor of the extinguishing device during switching of the circuit of the inductive energy store with a vacuum switch.

A diagram of the simplest extinguishing circuit, connected to the circuit of an inductive energy store, is shown in Fig. 1.

Curves of the recovery voltage and the current through the switch during discharge of the capacitor of the extinguishing circuit in a simplified form are shown in Fig. 2.

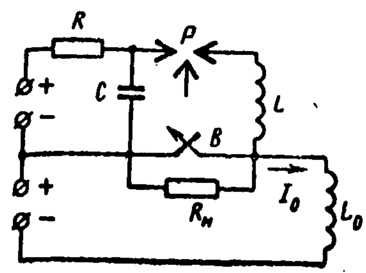

Fig. 1. Diagram of the switching of the circuit of an inductive energy store with a linear extinguishing circuit LC.

C - capacitor of the extinguishing circuit; L - choke of the extinguishing circuit; B - vacuum switch; L_0 - energy store; P - discharger; R - load resistance; R - charge resistance.

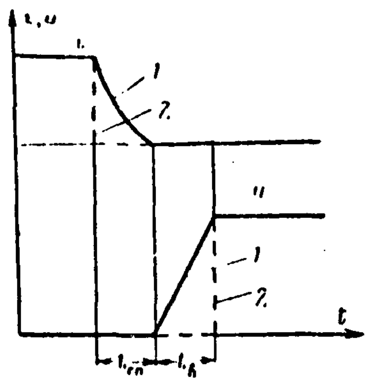

Fig. 2. Curves of the current and recovery voltage. 1 - in the presance of a linear extinguishing circuit LC; 2 - in the presence of an extinguishing circuit with a saturating choke.

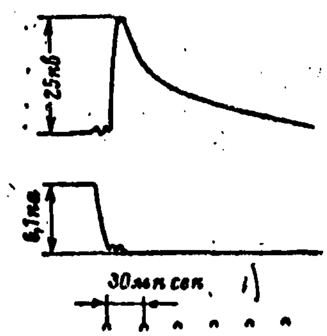

Fig. 3. Oscillograms of voltage and current in the circuit of a vacuum arc-extinguishing chamber (extinguishing circuit with a

saturating choke). KEY: 1. μs.

The duration of the switching process (as a result of which the current in the switch is decreased from I_0 to 0, and in the load increases from 0 to I_0) is determined by the sum of the time of current drop and the voltage recovery time:

$$t_{к} = t_{сп} + t_{в} = \frac{T}{4} + \frac{U_m C}{I_0} \alpha, \tag{1}$$

where T - period of oscillations of the extinguishing circuit; C - capacitance of the capacitor of the extinguishing circuit; I_0 - current to be switched; $U_m \approx I_0 R_H$ - maximum voltage on the load with a resistance of R_H; α - a certain coefficient depending on the moment of connection of the load (subsequently we shall consider that $\alpha \approx 1$, which is justified if the load is connected at the moment when the recovery voltage is close to U_m).

The minimum duration of switching necessary for successful disconnection may be examined as a characteristic of a switch of a given type.

Let us determine the dependence between energy for which the

capacitor of the extinguishing circuit must be designed and the duration of switching. The necessary capacitance of the capacitor of the extinguishing circuit is found from the relationship

$$C=\frac{TI_0}{2\pi U_0}, \tag{2}$$

where U_0 is the initial voltage on the capacitor of the extinguishing circuit. It is not difficult to show that energy E_1 stored in the capacitor of the extinguishing circuit will be minimum with $U_0=U$.

Taking into account (1) and (2) we find:

$$\begin{gathered}E_1=\frac{CU_m^2}{2}=\frac{t_k I_0 U_m}{\pi+2};\\ \frac{E_1}{E_0}=\frac{2}{\pi+2}\frac{t_k}{\tau}=0,39\frac{t_k}{\tau},\end{gathered} \tag{3}$$

where L_0 is the inductance of the energy store;

$$E_0=\frac{L_0 I_0^2}{2}=\frac{U_m I_0 \tau}{2};\quad \tau=\frac{L_0}{R_н}.$$

Thus the energy stored in the capacitor of the extinguishing circuit is proportional to the switching time. Relationship (3) may be written in a somewhat different form if we introduce the concept of the limiting frequency of the extinguishing circuit:

(4)

$$\frac{E_1}{E_0} \approx \frac{1}{2\pi f_{\text{пред}}\tau},$$

where

$$f_{\text{пред}} = \frac{1}{T} = \frac{1}{t_{\text{к}}}\left(\frac{1}{4}+\frac{1}{2\pi}\right).$$

Along with the simplest diagram of the extinguishing circuit examined above it is possible to use other diagrams which provide better conditions for extinguishing the arc in the switch. For example, in the presence of a saturating choke in the switch circuit [3] we observe that the current and the recovery voltage are approximately equal to zero during the switching period $t_{\text{к}}$. A similar effect takes place when we use an artificial line as the extinguishing circuit. It is not difficult to show that for the indicated diagrams the switching duration is equal to

$$t_{\text{к}} = \frac{2CU_m}{I_0}\ (\text{при}\ U_m \approx U_0).$$

The necessary energy of the capacitor of the extinguishing circuit is determined by a relationship analogous to (3):

(5) $$\frac{E_1}{E_0} = \frac{t_{\text{к}}}{2\tau}.$$

From relationships (3)-(5) it is evident that for evaluating the energy of the capacitor of the extinguishing circuit it is necessary to know the minimum switching duration t_{K} (or the limiting frequency $f_{пред}$). The indicated values were determined experimentally for vacuum arc-extinguishing chambers of the type KDV-12M. The diagram of tests is analogous to that shown in Fig. 1 with the difference that the current in the circuit of the tested chamber was created by discharging a bank of capacitors with a capacitance of C=1400 μF; the inductance of the store L_0 was 0.25 mH.

It should be noted that the employed method did not completely reproduce the conditions of operation of the switch in the circuit of the inductive energy store since in the process of testing a stage of prolonged passage of the current through closed contacts during the accumulation of energy was absent. For eliminating powerful heating of the contacts of the vacuum arc-extinguishing chamber it may be necessary to shunt it using a supplementary commutator, which breaks just before triggering of the vacuum switch.

During the tests the contacts of the vacuum arc-extinguishing chamber were separated simultaneously with the beginning of discharge of the capacitor bank which led to the appearance of an arc between them. The discharge of the capacitors of the arc-extinguishing circuit was realized at the moment when the distance between the

contacts of the chamber reached 2-3 mm. As a rule, this moment corresponded to the maximum current in the circuit of the chamber which arrived one millisecond after the beginning of discharge of the basic capacitor bank. In the course of the experiments it was established that the duration of burning of the arc between the contacts greatly affects the maximum switchable current. For example, with a decrease in the duration of burning of the arc from 4 to 1 ms the maximum switchable current increased approximately 1.5 times.

A relatively small arc time (1 ms) was achieved by rapid breaking of the chamber contacts using a special electrodynamic drive, consisting of two coils, mutually repelling each other during discharge on them of a capacitor with a capacitance of 100 μF charged to a voltage of 1.5 kV.

The resistance of the load connected through the discharger with a breakdown voltage of about 20 kV, was 5 Ω. The initial voltage on the capacitor of the extinguishing circuit was selected in the limits of 23-25 kV.

Along with the diagram depicted in Fig. 1 a diagram was tested with a saturating choke which was connected to the circuit of the arc-extinguishing chamber (in this case choke L was absent).

In the course of the experiments we recorded the current in the circuit of the vacuum arc-extinguishing chamber and the recovery voltage on an oscillograph (Fig. 3). The switched current was defined as the current preceding the moment of triggering of the extinguishing circuit. The limiting current was taken as the current corresponding to 90 $^{0}/_{0}$ successful disconnections. The switching duration was determined from the oscillograms from the moment of the initial current drop to the moment when the maximum recovery voltage was reached. The results of the tests have been reduced to a table.

1) Тип схемы	2) Емкость гасящего контура, мкф	3) Частота гасящего контура, кгц	4) Время коммутации, мксек	5) Предельный отключаемый ток, ка	6) Амплитуда восстанавливающегося напряжения, кв
7) С линейным дросселем	16	8,3	120	6	23
	4	13,5	50	5,8	24
	2	30	22	4,4	25
	1	47,5	15	3,1	25
8) С насыщающимся дросселем	16		32	6,3	23
	4		22	6,1	25
	2		15	4,2	24

KEY: 1. type of circuit; 2. capacitance of the extinguishing circuit; 3. frequency of the extinguishing circuit, kHz; 4. switching time, μs; 5. maximum switchable current, kA; 6. amplitude of recovery voltage, kV; 7. with linear choke; 8. with saturating choke.

In the absence of a load ($R_H = \infty$) the voltage may be restored to a very large value; in this case a breakdown occurred between the contacts of the chamber with a voltage of 35-46 kV.

From the table it is evident that the maximum switchable current depends little on the frequency of the extinguishing circuit in the limits of 8-14 kHz; a significant decrease of the switchable current occurred at frequencies of the extinguishing circuit of 30 kHz and greater.

With a given capacitance of the capacitor of the extinguishing circuit the use of a saturating choke makes possible a certain increase of the switchable current. It is interesting that with an increase of the duration of switching to 500 μs the switchable current rose only to 7 kA.

On the basis of the obtained data it is possible to select the switching duration and to evaluate the energy for which the capacitor bank of the extinguishing circuit must be designed. Apparently the use of a switch with an extinguishing circuit in the circuit of the inductive store is expedient under the condition that the energy of

the capacitors of the extinguishing circuit is at least an order less than the energy stored in the inductive store. From experimental data given in the table and from relationships (3)-(5) it follows that the indicated condition for the investigated vacuum switch will be observed if the duration of the discharge of the inductive store τ is hundreds of microseconds and greater.

(For example, with $f_{пред}=10$ kHz $\frac{E_1}{E_0}=0{,}1;\ \tau \geq \frac{1}{2\pi f_{пред} \frac{E_1}{E_0}} =$

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